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MEASUREMENTS OF TOTAL HEMISPHERICAL EMITTANCE FOR CHROMEL AND FOR ALUMEL WIRES

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16. Abstract

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MEASUREMENTS OF TOTAL HEMISPHERICAL EMITTANCE FOR CHROMEL AND FOR ALUMEL WIRES

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SUMMARY

The total hemispherical emittance for chromel and for alumel thermocouple wires has been measured over the approximate temperature range 556 K < T < 1333 K (1000° R < T < 2400° R) and at two representative surface conditions. If wire oxidation is suppressed by maintaining essentially an inert-gas test environment, the magnitude of emittance for a chromel and for an alumel wire remains relatively low compared with that for a more severely oxidized wire. Also, emittance increases less for alumel than for chromel wires for a change from a bright to an oxidized wire under comparable environmental conditions. The present results also indicate that emittance values are strongly dependent upon wire surface conditions.

INTRODUCTION

Bare-wire thermocouple probes are used for total-temperature surveys through boundary layers or in flow fields over test models. One advantage of these bare-wire probes over shielded probes is the smaller dimensions, determined mainly by the wire diameter. Since bare-wire probes are often fabricated and used essentially as cylinders in crossflow, extensive data on aerodynamic heat transfer and recovery temperatures for this configuration can be utilized to solve the heat-balance equation for the probes (ref. 1).

Although several wire materials are available for constructing thermocouple probes to withstand high-temperature environments, one of the most commonly used pairs for temperatures up to 1110 K (2000° R) is chromel and alumel. Probes using these materials can be designed for minimum heat conduction losses; however, radiant heat-transfer losses from such thermocouple probes become especially important at elevated temperatures and corrections due to radiation must be accurately calculated in addition to the heat conduction losses. Reliable data on the variation of emittance with temperature and with wire surface condition are therefore essential to the use of bare-wire probes in high-temperature environments.

Usually sufficient data exist on normal emissivity for individual base-metal wires at low temperatures (ref. 2) and some data are available on other wires at high tempera-

tures (refs. 3 to 7). However, at present little definitive data exist on total hemispherical emittance for chromel and for alumel thermocouple wires at high temperatures, that is, greater than 556 K (1000° R). Often, experimenters use constant values of emittance over a wide temperature range in their data-reduction procedure. To assess the possible error inherent in this procedure it is important to determine the effects of temperature and of wire surface condition on emittance.

This paper presents experimental data on the total hemispherical emittance for chromel and for alumel thermocouple wires over the approximate temperature range $556\ K < T < 1333\ K$ ($1000^\circ\ R < T < 2400^\circ\ R$) and at two representative surface conditions. Measurements of the temperature distribution along the wires were made to evaluate heat conduction losses. No other data of this type presently exist for chromel and for alumel wires except in reference 8 where emittance is inferred from measurements in high-velocity gases.

SYMBOLS

Measurements and calculations were made in the U.S. Customary Units. They are presented herein in the International System of Units (SI) with the equivalent values given parenthetically in the U.S. Customary Units.

D	diameter
E	voltage drop
I	current
L	wire length
T	temperature
ϵ_H	total hemispherical emittance
ρ	wire resistivity
σ	Stefan-Boltzmann constant

Subscripts:

a	ambient

m wire junction

s end value

APPARATUS AND PROCEDURES

The method employed in the present measurements was a steady-state electrically heated technique similar to that of reference 3. A schematic sketch of the wires and circuit used is shown in figure 1. A block diagram included in figure 1 indicates the equipment used and the method of data readout (ref. 3). All of the chromel and the alumel wires tested were 0.051 cm (0.020 in.) in diameter D. A test wire length L of 26.7 cm (10.5 in.) was needed to minimize conduction losses. Figure 1 shows an alumel test wire in place with three chromel wires 0.0076 cm (0.0030 in.) in diameter attached, one at the center and one at a distance of 1.27 cm (0.50 in.) on each side of the center. To obtain emittance data for a chromel wire, the alumel wire shown was replaced by a chromel test wire with three alumel wires 0.0076 cm (0.0030 in.) in diameter attached in the same positions.

Junctions of the chromel wires were made by resistance overlap welding so that no "bead" formed. The test wire was suspended freely between supporting posts 26.7 cm (10.5 in.) apart. The testing was done in an aluminum vacuum chamber 61 by 61 by 61 cm (2 by 2 by 2 ft), evacuated to pressures of about 1.33 N/m^2 (0.01 torr) or less with interior walls sprayed with optical black paint to reduce radiation effects. Power leads were copper wires 0.26 cm (0.102 in.) in diameter attached to both ends of the test wires. A 60-cycle alternating-current power supply was used to heat the wire. The current I was measured with a calibrated root-mean-square ammeter. The voltage drop E was measured across the central 2.54 cm (1.00 in.) of the test portion with a root-mean-square voltmeter.

A manually balanced precision potentiometer was used to measure the thermal electromotive force of the junction at the center of the wire relative to ambient temperature. A low-pass rejection filter isolated the potentiometer from the 60-cycle current. A back-to-back arrangement of the electrolytic capacitors prevented short circuiting of the thermal electromotive force by the secondary winding of the power transformer. The main source of error is the power supply. The uncertainty of the power supplied to the test wire is ±2 percent.

RESULTS AND DISCUSSION

Both chromel wires and alumel wires are subject to oxidation in air at temperatures higher than approximately 1110 K (2000° R) but still resist oxidation better than other

commonly used conventional base-metal thermocouples. In the present tests, purging of the vacuum chamber with high-purity nitrogen gas and outgassing, prior to each test, were done to reduce oxidation of the test wires. The nitrogen gas used for purging contained less than five parts per million of oxygen. Emissivity data obtained under these conditions are referred to as data for "bright" surface conditions.

The surface condition of chromel wires tested at high temperatures in a vacuum chamber that has not been purged changes from the original bright condition to a condition called "green rot" (ref. 2). Under such unpurged conditions the chromel wires change to a greater extent than the alumel wires. Furthermore, the surface of the chromel wires darkens with increasing exposure time and the indicated wire temperature level decreases for the same power setting when the test chamber is not purged with high-purity nitrogen gas. Results referred to as "oxidized" were obtained by subjecting the wires to this non-purged vacuum environment for fairly long time intervals (3 hr) at high temperatures, that is, at temperatures higher than 922 K (1660° R). It should be noted that the oxidized results presented do not represent a limit but are typical of slightly oxidized wires. The oxidized alumel wire surface was slightly discolored and relatively smooth in appearance. However, the chromel wire was completely discolored and the surface was covered with a greenish-yellow rough coating that could be removed easily with emery cloth.

Even though the test wires used were 26.7 cm (10.5 in.) in length to minimize conduction losses, differential temperatures (with respect to the junction temperature T_m) were measured along the oxidized alumel wire, which has the largest thermal conductivity. These measurements were obtained by attaching chromel wires 0.0076 cm (0.0030 in.) in diameter at the test wire center, at distances of 0.64 cm (0.25 in.) and 1.27 cm (0.50 in.) on each side of the center, and at a distance of 9.53 cm (3.75 in.) on one side of the center. Conduction effects along the alumel test wire were estimated by using these temperatures. The calculated maximum effect of conduction on emittance was 1.4 percent at the highest value of T_m and 0.45 percent at the lowest value of T_m. Therefore, no conduction corrections were made and, from measured values of I, E, T_a, and T_m, values of emittance were calculated from

$$\epsilon_H = \frac{IE}{\pi D L \sigma \left[T_m{}^4 - \left(\frac{T_a}{T_m}\right)^{1/2} T_a{}^4\right]} \tag{1}$$

which is given as equation (5) in reference 4.

The total hemispherical emittance for bright and for oxidized chromel wires and alumel wires is shown in figure 2 for typical runs on each wire. For either a bright or an oxidized alumel wire, the data in figure 2 could be repeated to within ±2 percent for the same test environment and procedure. This was also true for a bright chromel wire;

however, the emittance level did increase slightly for successive tests of the oxidized chromel wire. (See fig. 2.) Stabilization of the temperature of the test wire required approximately 1 minute at each power level. The present data indicate increasing emittance with temperature increase for both the chromel and the alumel wires. Also, the oxidized wires show considerably higher emittance values than the bright wires for the same temperature range. Shown for comparison, for bright chromel and for bright alumel wires, is a distribution of total hemispheric emissivity with temperature obtained from an expression derived as equation (2) in reference 4. This theoretical expression

$$\epsilon_H = 0.754(\rho T_m)^{1/2} - 0.635(\rho T_m) + 0.673(\rho T_m)^{3/2} \tag{2}$$

represents emissivity as a function of wire resistivity (calculated from measured values of I and E) and is valid only for a bright wire at low temperatures with a contamination-free wire surface. The computed values of resistivity agree with other similar data (ref. 2).

When the surface of a given wire specimen is altered from a bright uncontaminated condition, for which the emissivity of the material is defined, then no direct comparison with other wire specimens is completely valid unless the altered surface conditions are specified precisely. Furthermore, for a given wire specimen it is common to relate normal and hemispherical emissivity by a fixed ratio. Within these limitations the following table, with available normal-emittance values for chromel and for alumel wires, may be useful for general comparative purposes:

Normal emittance		Temperature		Nominal wire condition	Reference
Alumel	Chromel	K	$^{\circ}$R		
0.096		472	850	Bright	Private communication: Mr. H. D. Newton, Hoskins Manufacturing Company, Mar. 27, 1968
	0.35	972	1750		
0.186		1283	2310		
	0.64	333	600	Oxidized	
0.59		925	1665		
	0.76	1311	2360		
	0.89 to 0.82	543 to 833	978 to 1500	Highly oxidized	7 (p. 1315)
	0.87 to 0.89	373 to 1573	672 to 2832		

CONCLUDING REMARKS

It may be concluded that, with wire oxidation suppressed by maintaining essentially an inert-gas test environment, the magnitude of emittance for a chromel and for an alumel wire remains relatively low compared with that for a more severely oxidized wire. When a change from a bright to an oxidized wire under comparable environmental conditions occurs, the emittance for chromel wires increases more than for alumel wires. The present results indicate that emittance values strongly depend upon wire surface conditions.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., August 10, 1971.

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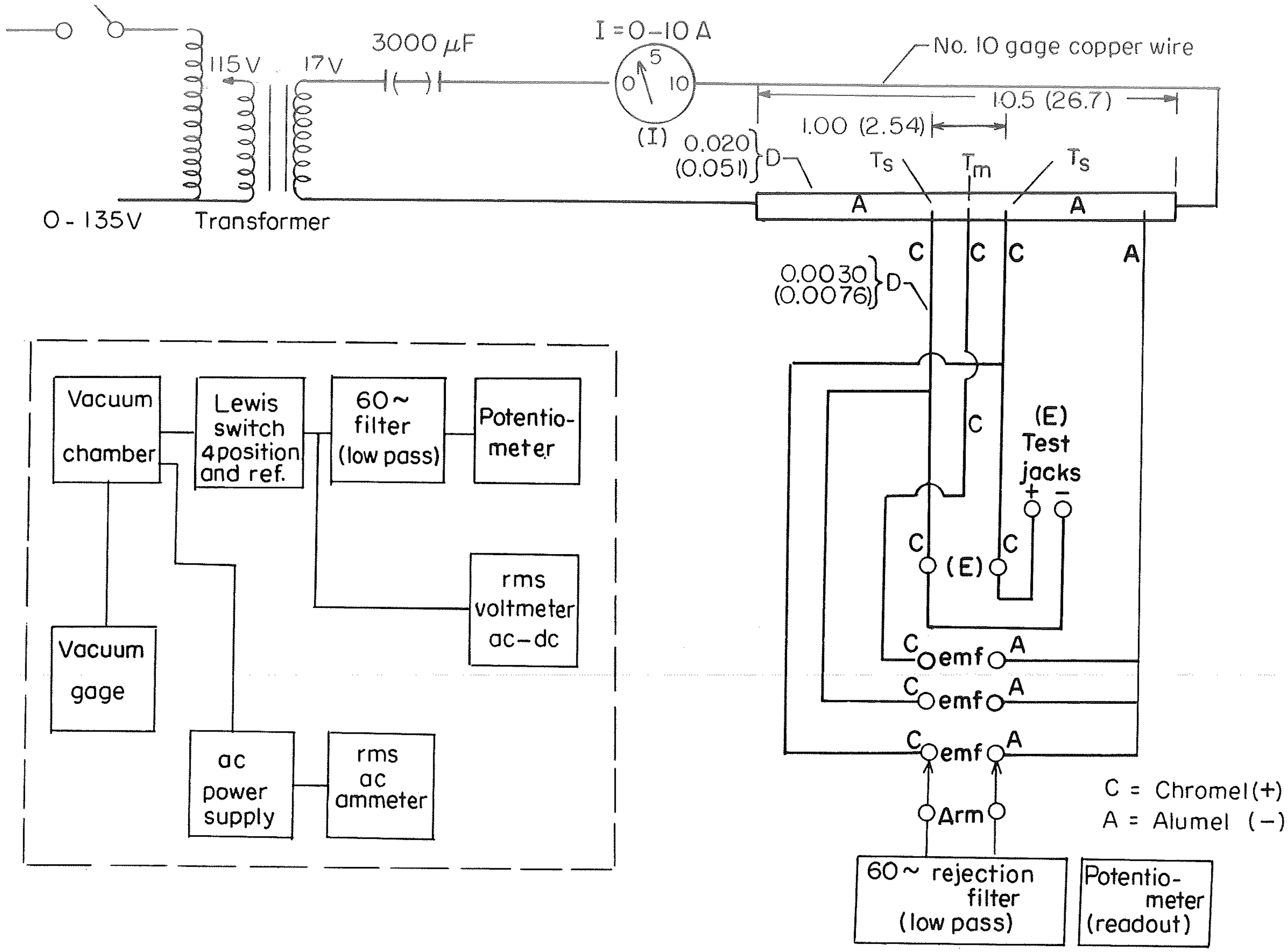

Figure 1.- Emittance apparatus and circuit. Dimensions in inches (cm).

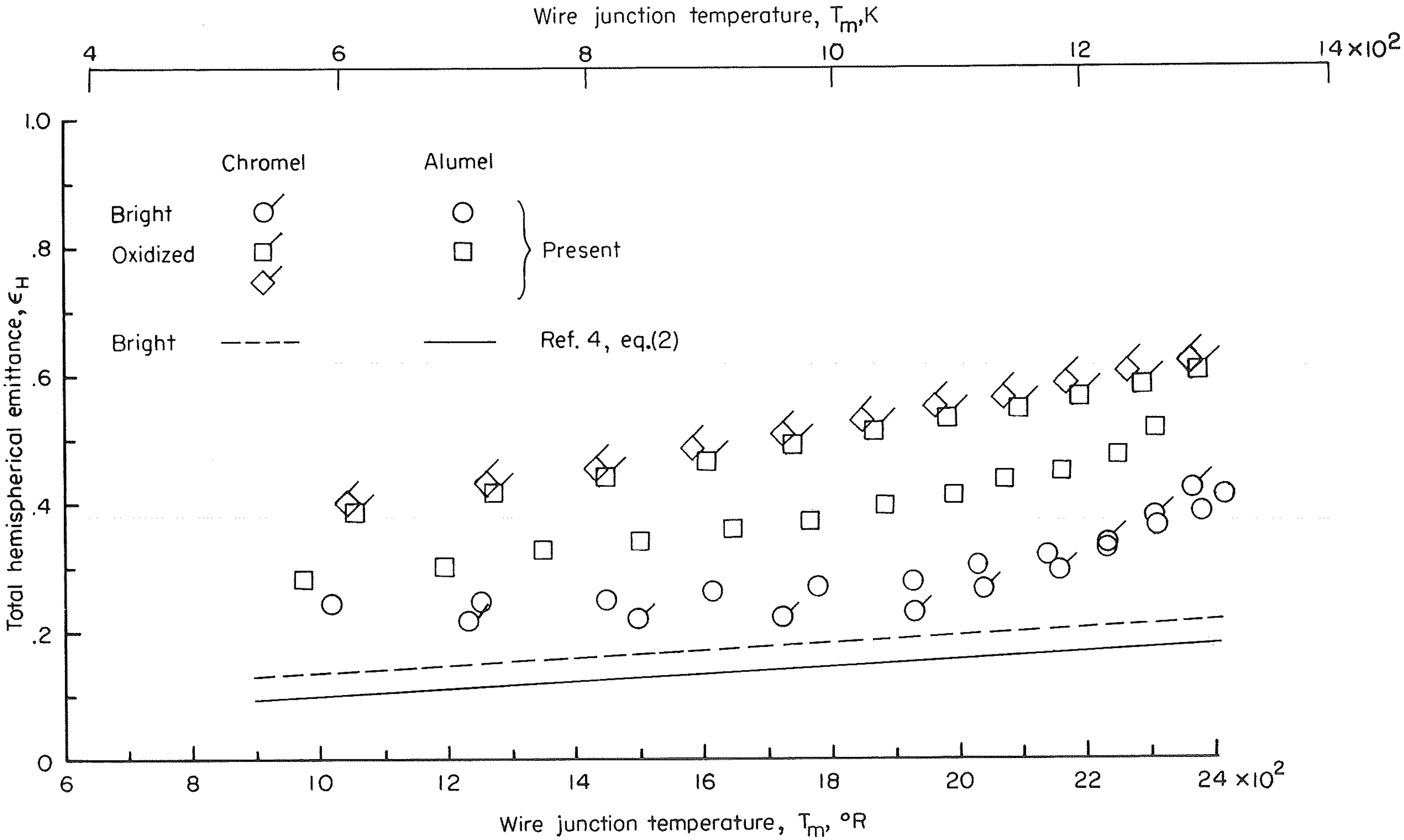

Figure 2.- Emittance for bright and for oxidized chromel wires and alumel wires.

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